

Short Introduction to Python

Machine Learning – Course Laboratory

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Why Python?



- Reasonable trade-off between a high-level language abstraction and computational efficiency
 - C/C++ is more efficient, but requires implementing at a lower abstraction level (e.g., considering memory allocation)
 - Matlab is maybe easier to program, but typically less efficient
- Python is a high-level programming language providing several third-party libraries that normally wrap C/C++ (efficient) code
- Availability of machine-learning libraries (scikit-learn.org)



scikit-learn
Machine Learning in Python

- Simple and efficient tools for data mining and data analysis
- Accessible to everybody, and reusable in various contexts
- Built on NumPy, SciPy, and matplotlib
- Open source, commercially usable - BSD license

PyCharm



- Development IDE <https://www.jetbrains.com/pycharm/>
- Easy to setup and use
 - Integration with repositories / versioning mechanisms (subversion, git)
- Compliant to PEP8 programming guidelines (after configuration)

The screenshot shows the PyCharm IDE interface with several components highlighted by black circles and arrows:

- Project files:** An arrow points to the 'Project' tool window on the left, which displays the file structure of the 'lab-material' project, including files like 'Ex_01.py', 'Ex_02.py', 'Ex_03.py', 'Ex_05_06.py', 'Python_1_list.py', 'Python_2_iterative_and_conditional.py', 'Python_3_functions.py', 'Python_4_numpy_array.py', and 'random_student_groups.py'.
- Editor:** An arrow points to the main code editor window, which displays the content of 'Ex_01.py'. The code includes an import statement for numpy, variable assignments for n_samples and n_features, random generation of x and y, and print statements for x and y.
- Python shell:** An arrow points to the 'Python Console' at the bottom left, which shows the execution output of the code in the editor, including the values of x and y.
- Variables:** An arrow points to the 'Variables' tool window on the bottom right, which displays the current state of variables in the scope, including n_features, n_samples, np, sys, x, and y.

Laboratory Outline (Tentative)

- Python basics (2 hours, today)
- Dataset manipulation
- Implementation of learning and classification algorithms
 - Nearest Mean Classifier (NMC)
- Performance evaluation using cross validation
- Parameter estimation using cross validation
- Evaluation of learning algorithms
 - Support Vector Machines (SVMs), decision trees, neural networks
- Application examples
 - Design of a complete machine-learning system
 - Student competitions

Student Evaluation: Laboratory assignment (4 hours)

We will use Python 3 during the course

Python Basics



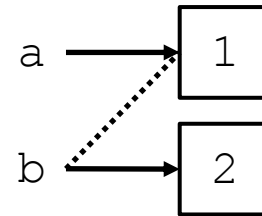
Data Types

- Base elements
 - **int** (e.g., `1`), **float** (e.g., `1.0`), **strings** (e.g., `"a word"` or `'a word'`)
- Lists
 - flexible arrays, can be modified *in place* (*mutable objects*)
 - `a = ['wolf', 'cat', 'horse', 1, 1.0, ['a', 'b'], 3]`
- Tuples
 - similar to lists, but *immutable* (faster indexing with hashing)
 - `a = ('wolf', 'cat')`
- Dictionaries (hash tables)
 - key-value pairs (keys are *immutable*, values are *mutable*)
 - `a = { 'key1': 0, 'key2': 1 }`
- Numerical arrays (we will see more on numpy arrays later on)

Basic Operations

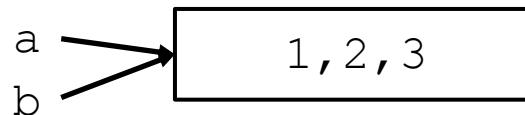
- Important: everything in Python is a variable
 - including functions, classes, modules
- Immutable objects can not be modified (reference changes!)

```
>>> a = 1
>>> b = a
>>> b = 2
>>> print a, b
1 2
```

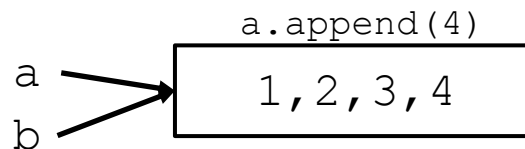


- Mutable objects (like **lists**) can be modified (by **in-place** functions)

```
>>> a = [1, 2, 3]
>>> b = a
```



```
>>> a.append(4)
>>> print b
[1, 2, 3, 4]
```



Basic Operations (Lists)

- Creation

```
>>> a = [1, 2, 3]
>>> a = range(0,5)
>>> print a
[0, 1, 2, 3, 4]
>>> a = range(0,5,2)
>>> print a
[0, 2, 4]
```

- Indexing

```
>>> a = [1, 2, 3]
>>> print a[0], a[1], a[-1]
1 2 3
>>> print a[1:] # slicing from index 1 to end
[2,3]
>>> print a[:2] # slicing from index 0 to 2 (excluded)
[1,2]
```


Basic Operations (Lists)

- Reference and copy

```
>>> a = [1, 2, 3]
>>> b = a # reference assignment. a and b are modified
>>> a[0] = 2
>>> print a, b
[2, 2, 3] [2, 2, 3]
```

```
>>> b = a[:] # this is a copy. now a and b are different
>>> a[0] = 2
>>> print a, b
[2, 2, 3] [1, 2, 3]
```

- Other operations

```
>>> a = [3, 1, 2]
>>> len(a) # returns number of elements in list
3
>>> a.sort() # sorts list in ascending order [1, 2, 3]
>>> a.append(4) # appends element at end -> [1, 2, 3, 4]
```

Control Structures

- **if** *condition*:
 statements

 elif *condition*:
 statements

 else:
 statements
- **for** *var in sequence*:
 statements
- **while** *condition is True*:
 statements

```
a=0
if a<0:
    print 'a is negative'
elif a>0:
    print 'a is positive'
else:
    print 'a is zero'
```

```
a=['a','b','c']
for elem in a:
    print elem
```

```
a = 5
while a > 0:
    a = a - 1
    print a
```

Functions / Procedures

```
def name(arg1, arg2, ...):  
    """documentation""" # optional doc string  
    statements  
    return # from procedure  
    return expression # from function
```

```
def gcd(a, b):  
    """greatest common divisor"""  
    while a != 0:  
        a, b = b % a, a # parallel assignment  
    return b
```

```
>>> print gcd(12, 20)  
4
```

Numpy Arrays (array)

```
import numpy as np

a = np.array([[1, 2, 3],
              [4, 5, 6]])

>>> a.shape
(2, 3)

>>> a.dtype
dtype('int64')

n_rows, n_cols = 2, 4
a = np.zeros(shape=(n_rows, n_cols))
>>> a
array([[ 0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.]])
```

Other Array Creation Methods

```
a = np.ones(shape=(n_rows, n_cols)) # creates matrix of ones
```

```
a = np.eye(n_rows, n_cols) # creates identity matrix
```

```
>>> a
```

```
array([[ 1.,  0.,  0.,  0.],  
       [ 0.,  1.,  0.,  0.]])
```

```
# random numbers from Normal distribution
```

```
# with zero mean and unit variance
```

```
a = np.random.randn(n_rows, n_cols)
```

```
# random numbers from Uniform distribution in [0,1]
```

```
a = np.random.rand(n_rows, n_cols)
```

```
>>> a
```

```
[[ 0.02413213  0.27179266  0.8904404  0.78110291]  
 [ 0.66329305  0.57972581  0.19168138  0.44013989]]
```

```
>>> np.random.randint(0, 5, [n_rows, n_cols]) # random integers
```

```
[[ 0  2  1  0]  
 [ 1  4  3  1]]
```

Array Indexing

- This can be rather complicated
 - <https://docs.scipy.org/doc/numpy/reference/arrays.indexing.html>
- Let's keep it simple, using some simple rules
 - Index arrays with shape = (n,) (flat arrays, vectors) with a single index
 - Index matrices with shape = (n, m) using two indices
 - In general, if shape.size == K, we should use K indices

```
a = np.eye(3)
>>> a
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])
>>> a[0, 0] # picks the first element (returns float)
1.0
>>> a[0, :] # picks the first row (returns flat array)
array([ 1.,  0.,  0.])
>>> a[:, 1] # picks the second column (returns flat array)
array([ 0.,  1.,  0.])
```

Array Indexing

```
a = np.eye(3)
```

```
>>> a
```

```
array([[ 1.,  0.,  0.],  
       [ 0.,  1.,  0.],  
       [ 0.,  0.,  1.]])
```

```
>>> a[0:2, 0:2] #selects submatrix with slicing operators
```

```
array([[ 1.,  0.],  
       [ 0.,  1.]])
```

```
b = np.array([1, 1, 0])
```

```
>>> a[b==1, :] # b used to index rows (picks first and second here)
```

```
array([[ 1.,  0.,  0.],  
       [ 0.,  1.,  0.]])
```

Other Operation on Arrays

```
a = np.array([1, 2, 3])
```

```
b = np.array([4, 5, 6])
```

```
>>> np.vstack((a, b))  # stack rows (vertical stacking)
array([[1, 2, 3],
       [4, 5, 6]])
```

```
>>> np.hstack((a, b)) # stack columns (horizontal stacking)
array([1, 2, 3, 4, 5, 6])
```

```
>>> a.dot(b)  # scalar product
32
```

```
# other operations include: reshape, transpose, min/max, etc.
# we will see more throughout the course, when required
```


Exercise 1

- Create an ndarray `x` of `shape=(5, 4)` with random numbers
 - Each of the 5 rows represents a sample with 4 features
- Create a flat ndarray `y` of `shape=(5,)`, whose elements are 0 and 1
 - Each element is the class label of the corresponding sample in `x`
- This is a simple example of a two-class dataset!

Hint: use `np.random.rand(...)` and `np.random.randint(...)`

```
x = [[ 0.33990211  0.94182274  0.66611658  0.72773846]
      [ 0.33281557  0.24280422  0.3627702   0.40495032]
      [ 0.5016927   0.29465024  0.61690932  0.25302243]
      [ 0.01744464  0.82521145  0.82226041  0.89858553]
      [ 0.33772606  0.17433791  0.7705529   0.11211808]]

y = [0 0 1 1 1]
```

Exercise 1: Solution

```
import numpy as np

n_samples = 5
n_features = 4

x = np.random.rand(n_samples, n_features)
y = np.random.randint(0, 2, n_samples)

print("x =", x)
print("y =", y)
```

Exercise 2

- Define a function `extract_subset(x, y, y0)` that takes as input:
 - the feature matrix `x`, and the labels `y` from the previous exercise
 - a target class `y0` (i.e., either `y0=0` or `y0=1`)
- and returns a feature matrix containing only samples belonging to `y0`

Hint: use *array indexing* with `y==y0`

```
x = [[ 0.33990211  0.94182274  0.66611658  0.72773846]
      [ 0.33281557  0.24280422  0.3627702   0.80495032]
      [ 0.5016927   0.29465024  0.61690932  0.25302243]
      [ 0.01744464  0.82521145  0.82226041  0.89858553]
      [ 0.33772606  0.17433791  0.7705529   0.11211808]]
```

```
y = [0 0 1 1 1]
```

```
>>> extract_subset(x, y, 0)
array([[ 0.33990211  0.94182274  0.66611658  0.72773846],
       [ 0.33281557  0.24280422  0.3627702   0.80495032]])
```

Exercise 2: Solution (cont'd from Exercise 1)

[code from Exercise 1]

```
def extract_subset(x, y, y0):  
    # we should do some checks to validate inputs  
    # e.g., to check if y0 is 0 or 1, etc.  
    # but we will address this problem later on  
    return x[y == y0, :]  
  
x0 = extract_subset(x, y, 0)  
print('x0 =', x0)
```

Exercise 3

- Define a function `min_feature_values(x)` that returns the minimum value of each feature in `x`
- Apply it on the previously-extracted samples `x0` of class 0

Hint: use `np.min()` with a proper `axis` value

```
x0 = [[ 0.33990211  0.94182274  0.66611658  0.72773846]
       [ 0.33281557  0.24280422  0.3627702   0.80495032]]
```

```
>>> min_feature_values(x0)
array([0.33281557  0.24280422  0.3627702  0.72773846])
```

Exercise 3: Solution

```
[code from Exercise 2]
```

```
def min_feature_values(x):  
    return np.min(x, axis=0)  
  
print('min. feat. values: ', min_feature_values(x0))
```

Exercise 4

- Define a function **make_gaussian_dataset** (`n0`, `n1`, `mu0`, `mu1`) that generates a two-class Gaussian dataset in a bi-dimensional space
 - `n0`, `n1` are the number of samples for class 0 and class 1
 - `mu0`, `mu1` are the means of the two Gaussians (one per class)
- We consider only Gaussian distributions with covariance equal to the identity matrix here for simplicity
- The function returns the corresponding feature matrix and labels `x`, `y`

Hints:

- use `np.random.randn(...)` to generate random numbers from a standard Gaussian distribution, with zero mean and unit variance, and then transform them to have a different mean (repeat twice, one per class)
- use `np.ones(...)` and/or `np.zeros(...)` for class labels
- use `np.vstack(...)` and `np.hstack(...)` to concatenate arrays

Exercise 4: Solution

```
import numpy as np

def make_gaussian_dataset(n0, n1, mu0, mu1):
    """ Creates a 2-class 2-dimensional Gaussian dataset. """
    d = 2 # hard-coded for convenience, we will improve this later on

    x0 = np.random.randn(n0, d) + mu0 # uses broadcasting...
    x1 = np.random.randn(n1, d) + mu1

    # sample labels
    y0 = np.zeros(n0)
    y1 = np.ones(n1)

    # concatenate data and labels
    x = np.vstack((x0, x1))
    y = np.hstack((y0, y1))

    return x, y

# generate data with 10 samples/class, and means [-1,-1], [1, 1]
xn, yn = make_gaussian_dataset(10, 10, [-1, -1], [+1, +1])
print('xn: ', xn)
print('yn: ', yn)
```